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Status Report
- 2003 Field Season –

McConnell Lakes White Pine Competition Studies

Doug Pitt, Bill Parker, Andree Morneault, Al Stinson, Wayne Bell, and Len Lanteigne

For further information, contact D. Pitt at dpitt@NRCan.gc.ca or 705-541-5610

Introduction

In 2000, the Canadian Ecology Centre Forestry Research Partnership (CEC-FRP) initiated two side-by-side experiments aimed at quantifying the effects of woody and herbaceous vegetation on white pine (*Pinus strobus* L.) establishment, growth, and stem quality. The first experiment was established subsequent to a clearcut harvest near Reynolds Lake, in the McConnell Lakes area of Northeastern Ontario, and is intended to represent the restoration of white pine to sites that have become dominated by other, less desirable species. White pine seedlings were planted and treatments initiated on this site in 2001. The second experiment was established subsequent to a shelterwood harvest in a stand adjacent to the first site, and is intended to represent conventional regeneration efforts where white pine are well represented in parent stands. White pine seedlings were planted and treatments initiated on this site in 2002. Through the support of the Spray Efficacy Research Group (SERG), J.D. Irving Limited, and the Canadian Forest Service-Atlantic, a third experiment was established subsequent to a shelterwood harvest near Doaktown, New Brunswick. Having somewhat different soils and management regimes, this third installation is intended to compliment the two Ontario studies and broaden experimental inferences.

The following document summarizes the research activities and preliminary results of these studies to date. This document is intended to be a supplement to the fact sheets, available on the Partnership website at http://forestresearch.canadianecology.ca, which detail objectives, experimental design, and methods for these two studies.

Background

Eastern white pine is one of Canada's most important tree species. It produces our region's largest trees and furnishes some of the world's most valuable wood products. White pine also provides critical habitats that are of tremendous ecological, wildlife, and social value.

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Unfortunately, white pine can be a difficult species to regenerate. In natural ecosystems, white pine thrives on frequent, low-intensity fires that expose moist seedbeds and kill balsam fir, trembling aspen, and other species that compete with seedlings for light, soil moisture, and nutrients. The absence of such fires, in combination with pressures from past harvesting practices, insects, diseases, and browsing have contributed to a significant reduction in white pine across our landscape during the past century (Aird 1985; Frelich 2002).

Through recent efforts to restore white pine to its historical range and harvest remaining stands in a manner that will ensure natural regeneration, foresters have identified the need for better understanding of how surrounding vegetation affects white pine seedling survival and growth. Just as our home gardens must be weeded to ensure success at harvest, so too must young white pine be kept free of competition for optimum growth. With this study, we aim to identify the vegetation components that most compete with white pine and the time during seedling development when competition is greatest, so that foresters may better target and time vegetation management efforts for the greatest success.

Study Objectives

The overall objective of this multi-year project is to educate practitioners through demonstration and the advancement of forest science. The specific project objective is to gain a better understanding of *how* and *when* to target vegetation management efforts to maximize white pine production and quality. This project will also demonstrate the need for and value of vegetation management in white pine regeneration, in both shelterwood and clearcut systems.

Some of the specific questions that this research aims to answer include:

- Does the presence of low-growing vegetation, such as grass, ferns, forbs, raspberries, and blueberries (collectively referred to herein as "herbaceous" vegetation) reduce the growth of white pine seedlings? If so, how long must this type of vegetation be suppressed for optimum growth?
- Do tall-growing arborescent species, such as trembling aspen and red maple (collectively referred to herein as "woody" vegetation), provide any early benefit to white pine seedlings (e.g., by mitigating climatic extremes)? If so, is there an optimum stem density range for these benefits?
- At what point during crop development, and at what density, does woody vegetation begin to negatively affect crop growth and stem quality?
- Does the presence or absence of herbaceous vegetation influence the effects of woody vegetation on the white pine seedlings?
- How far from optimal is the current operational practice of releasing white pine from both woody and herbaceous competition at the end of the second growing season?
- How does competition influence resource availability and white pine seedling physiology?
- How might vegetation management influence environmental conditions that favor white pine blister rust and weevil, two serious pests of white pine?
- How do the observed relationships differ under clearcut and shelterwood silvicultural systems?

Experimental Design

The study consists of a "response surface design" that combines different durations of herbaceous vegetation suppression (none, 2 years, and 4 years) with various timings of woody vegetation release (at time of planting, after the 2nd growing season, after the 5th growing season, and never). Once woody release occurs within the experiment, woody control is maintained through subsequent years (i.e., we assume no post-treatment hardwood regeneration or resprouting). Measured responses to the resulting treatment combinations will lead to a model or "response surface" that can be used by forest managers to develop vegetation management prescriptions aimed at optimizing white pine seedling growth and/or stem quality (Figure 1). The vegetation conditions that develop from the tested treatments will also allow forest managers to draw inferences about their potential impacts on factors such as wildlife habitat and diversity. Since hardwood density will likely influence the nature of the response surface, 3 different hardwood densities are being studied; 5000, 10000, and 15000 stems per ha – a response surface will be generated for each.

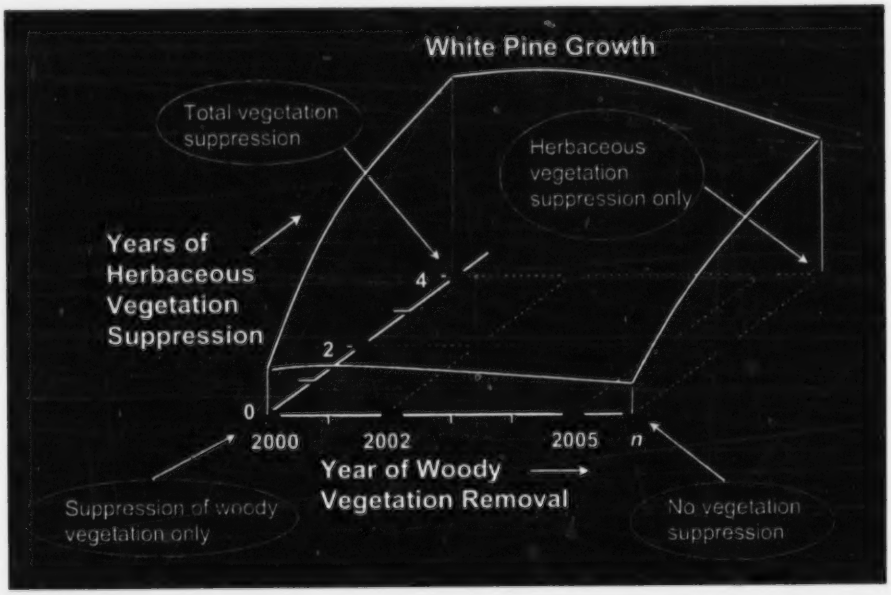

Figure 1. Theoretical response surface resulting from treatment combinations of duration of herbaceous vegetation control and timing of woody release.

The design employs key features of two established designs that have previously been applied to forest regeneration: the "4-corners" and "critical periods" designs. The 4-corners design (Miller *et al.* 1991) attempts to separate the competitive influences of woody and herbaceous vegetation through four treatments consisting of removal of 1) herbaceous vegetation, 2) woody vegetation, 3) both components, or 4) neither components. The "critical periods" design (Wagner *et al.* 1999) aims to identify the duration of herbaceous vegetation control required for optimum crop growth. Unfortunately neither of these

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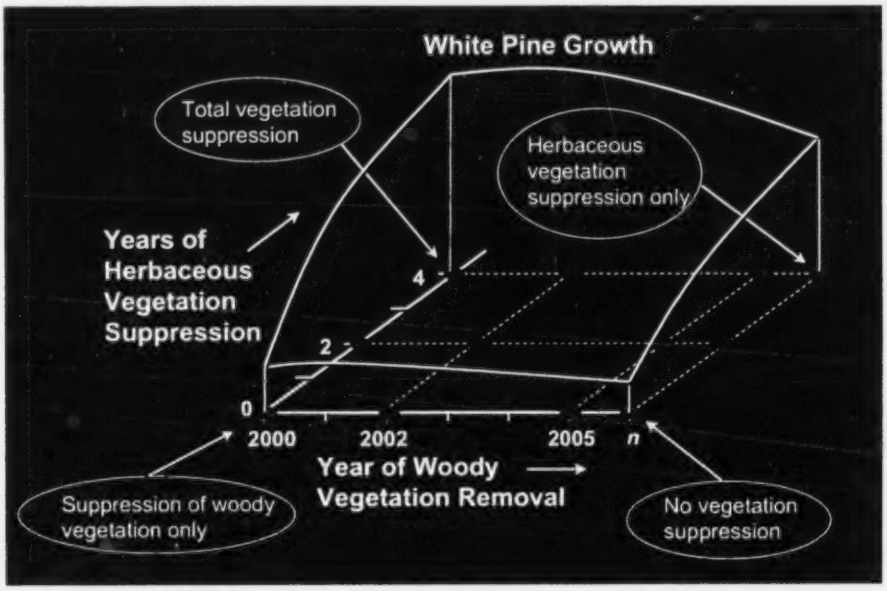

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original designs addresses operational situations where *both* woody and herbaceous vegetation are affecting the crop. Our design retains the 4-corner treatments and combines them with key "weed-free" herbaceous and "weed-infested" woody treatments of the critical-periods design. As comparative benchmarks, the design also includes continuous complete vegetation removal and conventional release after the second growing season.

The design is aimed at identifying optimal vegetation management strategies and not at comparing and contrasting vegetation management tools. Our intent is that foresters will emulate an optimum strategy suggested by the study results using one or more available vegetation management tools. Currently, with manual brushing or the application of 1 or more of Canada's 4 registered herbicides, it should be possible to emulate most of the 12 treatments identified above. For example, early herbaceous vegetation control may be achieved with a combination of mechanical site preparation and hexazinone treatment (soil texture permitting) or directed-foliar glyphosate application. Woody-only control might be achieved with manual brushing or a basal bark application of triclopyr. Combinations of herbaceous and woody control might be achieved with hexazinone site preparation, followed by broadcast release with glyphosate. Some combinations of longer-term herbaceous control and early woody release may point to the need for a new tool, such as a soil active herbicide capable of being applied to coarser-textured soils.

Plot layout and treatment application

Each installation of the design involves seventy-two 18-m x 18-m treatment plots. White pine seedlings are planted on these plots at 2-m spacing. Containerized greenhouse-grown aspen (and red maple on the two shelterwood sites) are also planted in the plots, where necessary, to augment natural stem densities and insure uniform woody competition levels across the plots. These stems are manually thinned on an annual basis to maintain the plots at their assigned stem density levels (5000, 10,000, or 15,000 sph). Vegetation control treatments are initiated and maintained, according to the study design, over the first 5 years. Herbaceous-only and complete vegetation control treatments are implemented using a combination of manual weeding and directed foliar applications of glyphosate (2% solution of Vision® applied with a backpack sprayer, equipped with a 16-18" wand and 8004 nozzle). Crop trees are protected with cups or plastic bags, when necessary, to prevent herbicide injury. Woody-only treatments are achieved with brush saw or basal bark treatments using the *streamline* method and the herbicide Release® (25 % product mixed in mineral oil and applied directly to the lower 30 cm of target stems with a backpack sprayer equipped with a 16-18" wand and a SS1502 nozzle).

The Ontario restoration (clearcut) site (Figure 2) was planted in spring of 2001 and has now completed its 3rd growing season. The adjacent shelterwood site (Figure 3) was scarified and prepared for planting in 2001 and planted in spring of 2002. The New Brunswick shelterwood site (Figure 4) is on the same timeline as the Ontario shelterwood site. The 2 shelterwood sites compliment each other in that they differ in soil type and residual stand density. The Ontario site is situated on deep, well-drained loamy sands and contains a mixture of red and white pine averaging 132 sph (18 m^2/ha); the New Brunswick site is situated on relatively shallow, sandstone-based, compacted tills, and contains relatively pure white pine averaging 97 sph (16 m^2/ha).

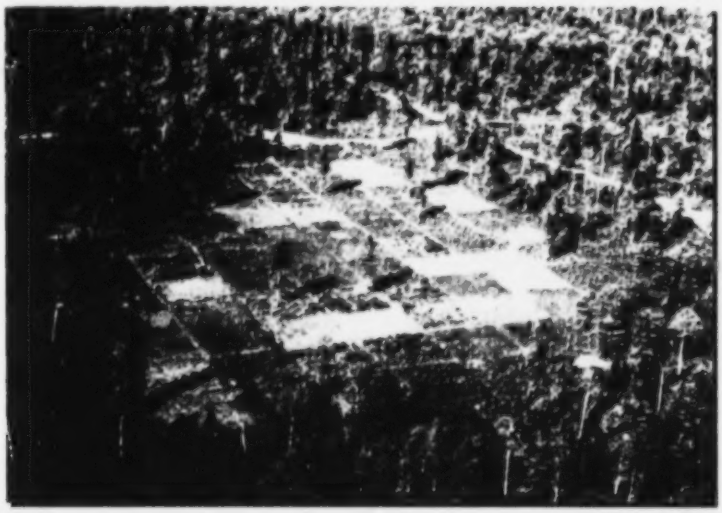

Figure 2. Aerial view of the Ontario restoration site, showing the layout of seventy-two 18-m x 18-m treatment plots. Photo taken September 2002.

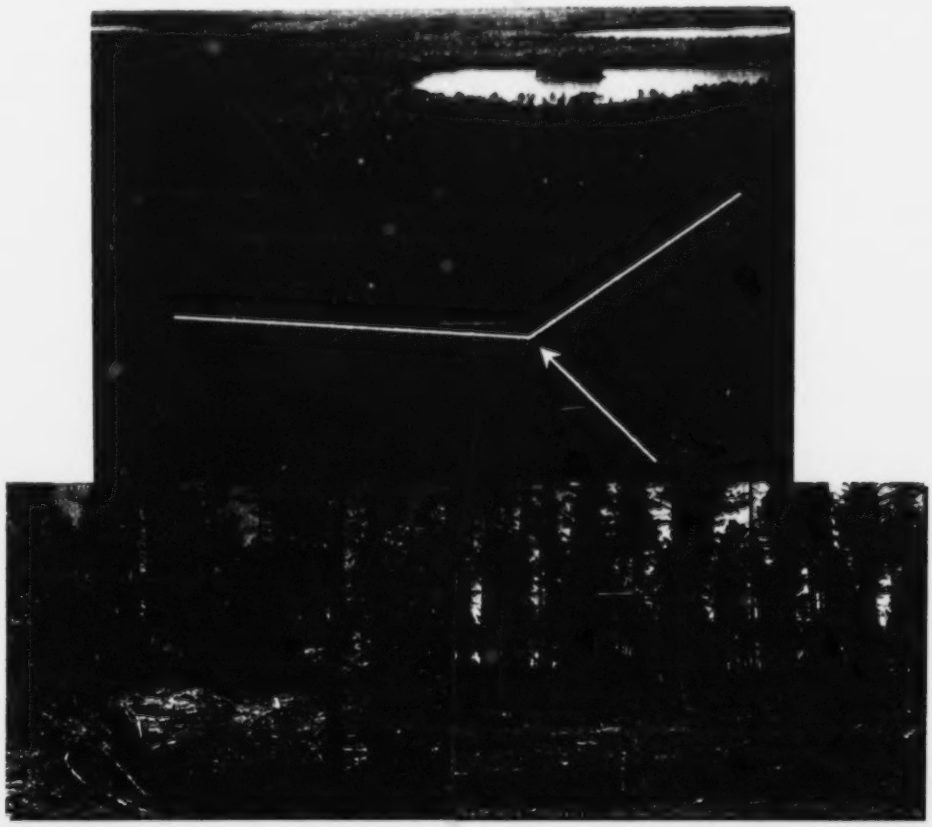

Figure 3. View of the Ontario shelterwood site before (left) and after (top and right) completing the seed cut (thinning from below) and scarification. Left photo taken August 2000; top and right photo taken June 2001.

Figure 4. View of the New Brunswick shelterwood site, vegetation control plot in foreground. Photo taken October 2003.

Summary of Ontario field activities 2003

Forest research technician Jorma Paloniemi was hired by the CEC-FRP to oversee field activities at the two Ontario installations in 2003. Jorma worked closely with a team of 6 Collège Boréal students to complete an extensive list of important field tasks. At the restoration experiment, these included 1) thinning aspen on the plots to the assigned treatment densities (5000, 10000, and 15000 sph); 2) maintaining vegetation control on the plots, where required by the assigned treatments (using both manual and chemical methods); 3) treating white pine seedlings with fungicide to prevent blister rust infection; and 4) conducting annual vegetation and crop-tree assessments. On the shelterwood site, activities included 1) fill-planting white pine seedlings (about 3% mortality); 2) thinning aspen and red maple on the plots to the assigned treatment densities (5000, 10000, and 15000 sph); 3) maintaining vegetation control on the plots; 4) treating white pine seedlings with fungicide to prevent blister rust infection; 5) conducting annual vegetation and crop-tree assessments, and 6) measuring the DBH, height, and crown diameters of overstory trees in the stand.

In addition to the core silvicultural work, microclimate stations were installed in each replicate of the "4 - corner" vegetation treatment plots in both the restoration (2001) and shelterwood (2002) study sites. Diurnal changes in air temperature, relative humidity, and light intensity, at 0.5 m above ground, soil temperature at 5 cm below ground, and volumetric moisture content of the top 15 cm of mineral soil, were measured annually thereafter, from early May through mid October. Separate microclimate stations were established adjacent to each study site to monitor atmospheric variables free of any treatment or overstory influence, as well as daily precipitation.

The relationship between percent vegetative cover and photosynthetic photon flux density (PPFD) at mean seedling height was established at both the restoration (26 cm height) and shelterwood (24 cm height) sites. A large number of treatment plots were selected for measurement to provide a broad range in percent cover (restoration site, *n*=23; shelterwood site, *n*=28). On days with uniformly overcast skies, PPFD was measured at seedling height and above the canopy of all understory vegetation, at the same time and locations where visual vegetative cover estimates were made. The ratio of below to above canopy PPFD for each individual measurement interval was averaged to provide an estimate of mean daily percent PPFD, or light availability. The relationship between light availability at seedling height and percent vegetative cover was then defined using linear regression. Understory light measurements in the shelterwood provided additional data to previous efforts aimed at quantifying the relationship between overstory canopy cover, residual stand basal area, and understory light levels.

Competition treatment effects on gas exchange characteristics (e.g., photosynthesis, transpiration) and leaf water status of white pine seedlings were determined on the restoration and shelterwood site on 3 and 4 days in the 2003 growing season, respectively. These ecophysiological variables were measured on days with clear skies, using a portable photosynthesis meter and a pressure chamber. Five pine seedlings per plot were sampled in the "4-corner" treatment plots (*n*=60), with different seedlings sampled on each measurement day.

Summary of New Brunswick field activities 2003

During 2003, a total of 25 person-weeks was devoted to a variety of tasks such as 1) fill-planting white pine seedlings (approximately 8% mortality); 2) thinning aspen and red maple on the plots to the assigned treatment densities (5000, 10000, and 15000 sph); 3) maintaining vegetation control on the plots; 4) conducting annual vegetation and crop-tree assessments, 5) measuring the DBH, height, and crown diameters of overstory trees in the stand, and 6) maintenance of plot and treatment identification. Individuals involved in the project included CFS-AFC personnel Len Lanteigne and Charles Weaver; students Travis Halliday and Jason Hallett; and casual technicians Charles Holmes, John Dixon, and Rob Stewart.

Synopsis of early results

Restoration experiment

The experimental design used in these studies contains 14 treatments that involve 3 durations of herbaceous vegetation control (0, 2, or 4 years), in combination with 4 different timings of woody release (at the time of planting, end of the 2nd growing season, end of the 5th growing season, or none) (Figure 1). Through to the end of the end of the 3rd growing season, however, these 14 treatments can be categorized into 1 of 10 possibilities illustrated in Figure 5. These treatments can be denoted by a simple 3-character code, with each character referring to no vegetation control (O), woody vegetation control (W), herbaceous vegetation control (H), or both (B), in each of the 3 years. Treatments OOO, WWW, HHH, BBB, BBW, and OOB are illustrated in Figures 6 through 11, respectively.

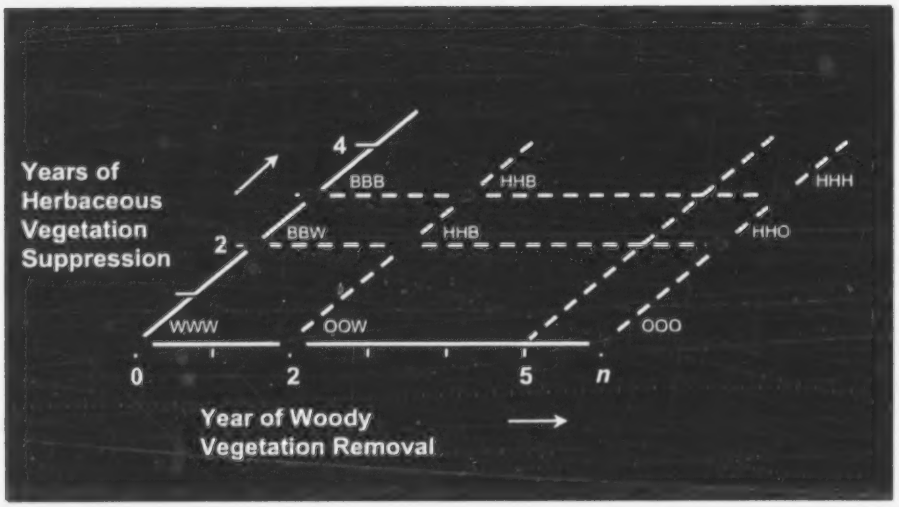

Figure 5. Response surface treatments at the end of the 3rd growing season. Treatment codes are comprised of "O" no vegetation control; "W"=woody control; "H" herbaceous control, and "B"=both woody and herbaceous control, with 3 characters representing years 1, 2, and 3. Operational release at the end of the second growing season is coded "OOB".

A total of 12 plots in the experiment existed in an untreated state at the end of the 3rd growing season (OOO). These plots were characterized by average covers of 70% fern, 15% grass, 10% broadleaf herbaceous plants, 20% low-shrubs, and 17% aspen (Table 1). With combined cover averaging over 85% (Figure 6), it is not surprising that these plots supported white pine seedlings that tended towards the smallest observed averages, with mean stem diameter of 8 mm, height of 33 cm, crown diameter of 22 cm, and stem volume index of 6 cm^3 (Table 2; Figure 12). Elevated seedling mortality has not yet appeared in these plots, with current values falling very close to the overall experimental average of 2%.

Removing only the woody vegetation (aspen) at the end of the second growing season (OOW), or at the time of planting (WWW; Figure 7) resulted in little change in total vegetation cover over untreated plots at the end of the 3rd growing season (average 84-85%). Correspondingly, we observed very small, statistically insignificant, increases in white pine stem size in response to these woody removals (Table 2; Figure 12). At this point in time, these results suggest that vegetation management strategies targeted only at the woody complex (e.g., site preparation or release using a brush saw) may not produce appreciable white pine growth response.

In contrast to untreated and woody vegetation control plots, those receiving only herbaceous control for 3 consecutive years (HHH) contained an average of 44% aspen cover at the end of the 3rd growing season (Figure 8). This light overhead cover, averaging 104 cm in height, appears to promote both seedling health and stem height, with the highest observed values coming from these plots (Table 2). Seedlings in

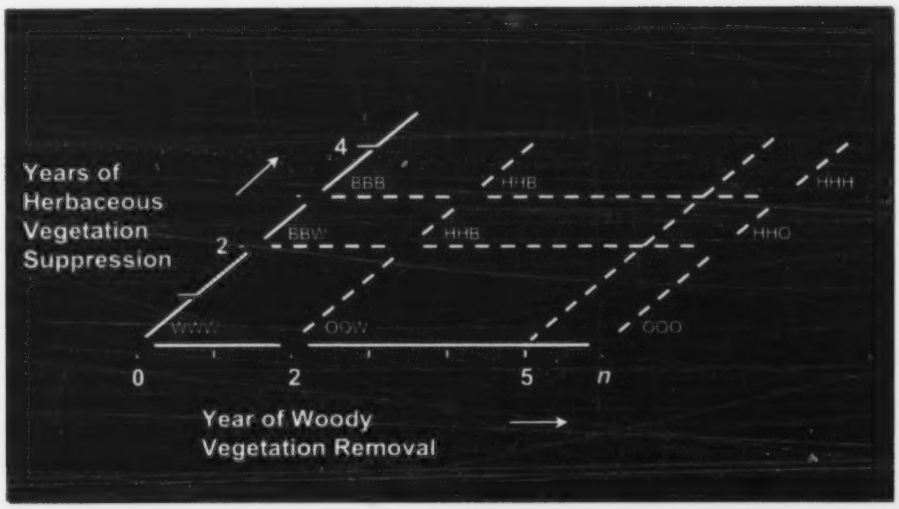

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Table 1. Summary of cover values (%) for major vegetation groups present on the restoration site at the end of the 3rd growing season.

Treatment	Ferns	Grass	Forbs	Low Shrubs	Deciduous	Total Veg Cover	Planted Pine	*n* plots
OOO	70	15	10	20	17	88	1	12
OOW	72	8	6	24	0	85	1	3
WWW	74	8	2	28	0	84	1	3
HHO	15	11	1	1	38	55	2	12
HHW	10	11	<1	1	0	20	2	9
BBW	1	20	1	<1	0	23	2	3
HHH	<1	<1	<1	<1	44	45	3	12
HHB	<1	<1	<1	<1	0	<1	2	3
BBB	<1	<1	<1	<1	0	<1	2	6
OOB	1	1	<1	<1	<1	3	1	9

Table 2. Summary of growth statistics for planted white pine on the restoration site at the end of the 3rd growing season.

Treatment	Health Code[1]	D5[2] (mm)	SE[3]	HT[4] (cm)	SE	SVI[5] (cm^3)	SE	CD[6] (cm)	SE
OOO	1.6	7.8	0.5	33.1	2.0	6.1	2.8	22.0	1.5
OOW	1.6	8.0	0.9	33.1	4.0	6.4	5.6	21.8	3.0
WWW	1.9	9.0	0.9	30.5	4.0	7.4	5.6	21.6	3.0
HHO	1.3	12.8	0.5	47.5	2.0	24.4	2.8	39.6	1.5
HHW	1.4	15.9	0.5	43.2	2.3	34.2	3.3	39.9	1.7
BBW	1.4	17.5	0.9	47.6	4.0	50.5	5.6	37.4	3.0
HHH	1.3	14.5	0.5	51.0	2.0	34.1	2.8	40.3	1.5
HHB	1.3	15.9	0.9	46.6	4.0	34.4	5.6	41.7	3.0
BBB	1.5	18.4	0.6	46.4	2.8	47.5	4.0	37.1	2.1
OOB	1.6	10.7	0.5	34.4	2.3	12.4	3.3	28.9	1.7

[1] Average of rankings ranging from 1=Vigorous, 2=Healthy, 3=Mediocre, 4=moribund, and 5=dead.
[2] Stem diameter, measured 5 cm above ground level.
[3] Standard error of the least squares mean.
[4] Stem height, measured from ground level to the tip of the terminal bud.
[5] Stem volume index, assuming conical form.
[6] Crown diameter.

these plots averaged 15 mm in diameter, 51 cm in height, 40 cm in crown diameter, and 34 cm^3 in stem volume (Figure 12); the latter amounting to more than 5-fold increases over untreated trees and 4-fold increases over trees relieved of overtopping woody competition. It is interesting that aspen on these plots

responded to herbaceous vegetation control as well, with height and stem diameter gains of 17% and 33%, respectively, resulting in 2-fold increases in stem volume. These early results indicate that foresters should not ignore the suppression of the low-growing vegetation complex – broadleaf plants, ferns, grasses, and low-shrubs – in their vegetation management prescriptions for white pine.

When early herbaceous vegetation control was combined with 2nd season woody removal, freeing the white pine from overhead shading (HHB), we observed small stem diameter (average 16 mm) and volume responses (Table 2; Figure 12), although these differences were not statistically significant. Relieving both woody and herbaceous competition at the time of planting (BBB; Figure 9), however, resulted in some of the largest stem diameters (average 18 mm) and volumes observed (Table 2; Figure 12). At this time, early woody and herbaceous vegetation control has amounted to nearly 8-fold increases in stem volume over no treatment, and more than 6-fold increases over woody-only control. While there are some indications of health and height growth (and, possibly, stem form) benefits associated with a woody overstory, it is clear that near competition-free conditions during early establishment results in the best overall white pine growth.

At this point, there are no statistical differences between the growth of seedlings in plots receiving 2 versus 3 years of relief from herbaceous competition, regardless of woody vegetation status (Figure 12). In just a single growing season on these plots, however, fern cover increased by an average of 1 to 14% and grass cover increased by 11 to 20% (Table 1; Figure 10). Forb and low shrub cover were slower to respond. It will be interesting to see if the white pine in these plots will be able to maintain future dominance over this rebounding vegetation.

Operational release with glyphosate after the second growing season (OOB) has resulted in trees that average 11 mm in diameter, 34 cm in height, 29 cm in crown diameter, and 12 cm^3 in stem volume (Figures 11 and 12). Although these values are slightly larger than untreated trees in all cases, they do not differ from the latter statistically. In just 2 growing seasons, these trees exhibited signs of suppression by the competition and it will likely be several years before they respond to release – assuming that rebounding competing vegetation does not overtake them in the interim. This is could be an important warning to those who wait even longer before releasing their white pine from competition. At this point, our study provides strong evidence that early competition control offers greater growth benefits than later control.

As suggested by the growth responses observed, vegetation control treatments had a strong influence on the above- and below-ground seedling microenvironment (Table 3). Continuous control of both herbaceous and woody vegetation since the time of planting (BBB), and woody vegetation control, alone (WWW), resulted in comparatively higher mean daily light intensity (PPFD) measured at 0.5 m above ground level. Mean daily soil temperature (Ts) was higher where herbaceous vegetation (HHH) and both vegetation types (BBB) were controlled. Warmer soils following these two treatments could contribute to increased mineralization rates and greater nitrogen availability to white pine seedlings. Greater soil warming in the spring may also result in earlier growth initiation in these treatments. Soil moisture levels in the top 15 cm of mineral soil (SMC) were also influenced by vegetation control, particularly during seasonal periods of reduced precipitation (Figure 13). For 3 consecutive years, control of both woody and

herbaceous vegetation has resulted in maximum soil moisture availability during mid-summer drought periods, hence minimizing negative physiological effects of water stress on seedlings in these plots. In contrast, the influence of remaining vegetation control treatments has changed over time. During the first growing season, when aspen leaf area was minimal, soil moisture in herbaceous control plots was similar to complete vegetation control plots. Over time, as the aspen have increased in size, leaf area, and transpirational demand, soil moisture in the herbaceous control plots has approached levels observed in the woody control and untreated plots (Figure 13; Table 3). It will be interesting to see whether or not increasing completion for moisture in these plots will ultimately deplete the growth advantage herbaceous control currently has over woody control or no vegetation control.

The abundance of competing vegetation had a significant effect on light availability at seedling height. Light available to white pine seedlings, expressed as mean daily percent sunlight, exhibited a negative linear relationship with percent vegetative cover at 26 cm above ground level (Figure 14). White pine seedlings require at least 25% sunlight for positive shoot growth and exhibit maximum height growth at about 50% sunlight (Logan 1966). Using these threshold values and the linear relationship observed, vegetation control treatments that reduce cover to around 80% would support positive shoot growth of pine, but reduction of cover to 60% is required to obtain maximum height growth. For example, 3rd year seedling height of white pine was < 33 cm in the OOO, OOW, and WWW treatments that had total percent cover values > 80% (Tables 1 and 2). Reduction of total cover to < 60% in several treatments was associated with seedling heights of 43 to 51 cm.

Vegetation control treatments had a strong influence on the physiology of white pine seedlings through effects on light and soil moisture in the 2nd and 3rd growing seasons. Net photosynthesis (Pn), leaf conductance of water vapour (Gwv), and water use efficiency (WUE, the ratio of CO_2 fixed in photosynthesis to H_2O transpired) differed among treatments in one or both growing seasons (Table 4). Treatments had much less influence on leaf water status measured before sunrise (LWPpd) or at midday, when gas exchange was measured (LWPmid). Vegetation control enhanced photosynthetic activity by increasing light and soil moisture availability. In both growing seasons, Pn exhibited a linear decrease with increasing percent cover of competing vegetation, due both to reduction in PPFD and soil moisture (Figure 15). The comparative treatment effects on Pn were similar to that observed for pine seedling size, suggesting that improved light and soil moisture availability improved growth through enhanced photosynthetic activity. In general, photosynthetic capacity and seedling growth potential were enhanced by complete vegetation control and, to a lesser extent, herbaceous vegetation control.

Table 3. Summary of seasonal averages for above- and below-ground environmental variables on the restoration site during the 3rd (2003) growing season (soil moisture content also provided for 2001). Means followed by the same letter are not significantly different (Tukey's HSD, $\alpha = 0.05$).

Treatment	PPFD[1] (mol d^{-1})	Ta[2] (°C)	VPD[3] (kPa)	Ts[4] (°C)	SMC[5] 2001 (%)	SMC[5] 2003 (%)
OOO	21.8b	14.4ab	1.17a	14.3b	10.9b	11.6b
WWW	34.0a	14.2b	1.15a	14.3b	10.3b	10.7b
HHH	22.8b	14.6a	1.18a	15.3a	13.4ab	11.6b
BBB	35.4a	14.3ab	1.11a	15.8a	15.3a	16.0a

[1] PPFD = Light intensity (photosynthetic photon flux density) measured 0.5 m above ground level.
[2] Ta = Air temperature measured 0.5 m above ground level.
[3] VPD = Vapour pressure deficit measured at 0.5 m above ground level.
[4] Ts = Soil temperature measured at 5 cm depth in the mineral soil.
[5] SMC = Soil moisture content averaged over the top 15 cm of mineral soil during mid-summer drought period, July 12 - August 16 (2001) and August 5 – September 15 (2003)

Table 4. Summary of seasonal mean values for leaf gas exchange and water status of white pine seedlings on the restoration site during the (a) 2nd (2002) and (b) 3rd (2003) growing seasons. Means followed by the same letter are not significantly different (Tukey's HSD, $\alpha = 0.05$).

Treatment	Pn[1] (umol CO_2 m^{-2} s^{-1})	Gwv[2] (mmol H_2O m^{-2} s^{-1})	WUE[3] (umol CO_2 umol H_2O)	LWPpd[4] (MPa)	LWPmid[5] (MPa)
(a) 2002					
OO	4.00c	102.6a	52.7b	-0.83a	-1.77a
WW	5.06c	100.6a	66.1a	-0.92a	-1.87a
HH	7.95b	127.6a	50.9b	-0.76a	-1.78a
BB	9.43a	140.2a	69.0a	-0.89a	-2.06b
(b) 2003					
OOO	3.39c	80.4c	41.3a	-0.53a	-1.58a
WWW	4.25c	93.7bc	43.6a	-0.66a	-1.76a
HHH	6.17b	104.2b	60.3a	-0.55a	-1.65a
BBB	7.77a	132.0a	57.7a	-0.59a	-1.67a

[1] Pn = Net photosynthesis at midday.
[2] Gwv = Leaf conductance of water vapour at midday.
[3] WUE = Water use efficiency (ratio of CO_2 fixed in photosynthesis to H_2O transpired) at midday.
[4] LWPpd = Leaf water status, measured before sunrise.
[5] LWPmid = Leaf water status, measured at midday.

Shelterwood experiments

On the Ontario shelterwood site, the operational seeding cut took place in 1999, leaving a high-quality, mature overstory of white and red pine, as well as many subordinate stems of spruce, balsam fir, maple, and aspen (Figure 3). In the fall of 2000, we completed the seeding cut by thinning the stand from below, to emulate what would be conducted under an intensive forest management regime. In all, the original stand density was reduced by 66%, to 132 sph (Figure 16), and BA was reduced by 53%, to 18 m^2/ha (Figure 17). The average diameter (DBH) of the residual stand is 42 cm, with several stems exceeding 60 cm. Stand age is 100 years.

The objective of tree marking in this stand was "half-crown spacing", which should have resulted in overstory crown closure approaching 35%. Our crown measurement data indicate that residual crown closure is closer to 50% (Figure 18), which is equivalent to about 1/4–crown spacing. Average crown diameter of the white pine was 7.7 m. Actual understory light levels within plots differing in basal area and crown closure were very similar, ranging from 40 to 65% sunlight (Figure 19). Although the relationship of understory light conditions with basal area and crown closure is best examined at a larger spatial scale (i.e., stand vs. plot level), these data illustrate the advantage of thinning from below in achieving target understory light levels for white pine regeneration. Prior to our completing this cut, light levels would undoubtedly have been below thresholds for optimum white pine seedling growth. Understory light levels in unmanaged, white pine dominated conifer stands in Ontario can be as low as 10% (Burgess and Wetzel 2000, Parker unpublished) – a level where seedling growth potential is greatly reduced and shade-induced mortality is initiated (Logan 1966, Kobe et al. 1995). These data serve as an operational reminder that, during a white pine seed cut, a true thinning from below is essential for creating sufficient light conditions for regeneration – particularly if relatively high BAs (16 m^2/ha +) are left in the overstory.

On the New Brunswick site, the residual stand is nearly pure white pine, with a total of 97 stems per ha (Figure 20). Although this stand density is somewhat lower than observed on the Ontario site, stems and crown sizes are larger, averaging 48 cm in DBH and 10.2 m in crown diameter, and resulting in greater overall residual crown area 7778 m^2/ha. Basal area on the site averages 15 m^2/ha for white pine, with an additional 1 m^2/ha in white birch, red maple, and red pine. Although we have not conducted light measurements on the New Brunswick site, these mensurational data suggest higher crown closure levels than the Ontario site and, potentially, lower understory light levels.

Through to the end of the second growing season, all of the vegetation treatments on the shelterwood experiments can be categorized into 1 of 4 possibilities (4-corner treatments): 1) no vegetation control; 2) woody-only control; 3) herbaceous-only control, or 4) total vegetation control. Following the same notation used above for the restoration site, OO, WW, HH, and BB will denote these treatments, respectively. The vegetation conditions that result from these treatments are illustrated for the Ontario shelterwood site in Figures 21 through 24, respectively.

Although the 3 installations of this study were not designed for between-installation statistical comparisons, there appear to be some overstory-related patterns developing with the understory

vegetation components (Table 5). In the second growing season, ferns, low shrubs, and total vegetation cover on untreated plots tended to be greatest on the restoration site and lowest on the shelterwood sites, corresponding with increasing overstory cover. Forb and deciduous cover, in contrast, tended to be highest on shelterwood plots and lowest on the restoration site. Regardless, total vegetation cover in excess of 68% on the shelterwood sites is creating a highly competitive environment for white pine, especially when overstory light interception is considered.

After 2 growing seasons, patterns in crop growth on the shelterwood sites appear to be similar to what was observed on the Ontario restoration site, at the same point in time (Table 6; Figure 25). Despite some herbicide damage occurring on white pine at the New Brunswick site, herbaceous competition control and complete competition control have resulted in the greatest white pine growth responses. Notably, overall seedling height growth was greater in the shelterwood sites than in the more open restoration site. This could be an overhead shading response, similar to the situation observed in herbaceous competition control plots of the restoration site.

In general, white pine seedlings in these shelterwoods are quite healthy, with no statistically significant differences arising between the major treatment groups. Overall mortality is less than 1% in the Ontario shelterwood and 7% at the New Brunswick site. At the Ontario site, an insect that we believe is a *fascicle mite* (possibly *Trisetacus alborum*) is causing a yellow spot on the side of the current year's leader of approximately 30% of the planted white pine. Some of these spots form scar tissue and, occasionally, the leader bends or breaks at the scarred point. We are in the process of making a positive identification of this pest and researching potential control strategies.

Natural regeneration of white pine and other conifers is prolific at both shelterwood sites (Figure 26). At the end of the second growing season at the Ontario site, white pine and red pine averaged 13,000 and 8000 sph, respectively, with an additional 6500 sph unidentified pine germinants. There are currently no statistically significant differences in these regeneration densities between the main treatment groupings. At the at the New Brunswick site, however, herbaceous vegetation control and herbaceous + woody vegetation control have apparently reduced seedling numbers from an average of 17,000 sph to 700 sph. This difference is likely due to the fact that the Ontario plots were weeded manually during the active growing season, while the New Brunswick plots were treated with glyphosate (3% solution). The Ontario data suggests that foresters should not delay conifer release in their shelterwoods for fear of killing young white pine seedlings. It is likely that this study will show that the benefits of early release will far outweigh any losses associated with herbicide damage.

Vegetation control treatments had comparatively less influence on the above- and below-ground seedling environment on the shelterwood site, due to the effect of the overstory on the amount of solar radiation transmitted through the canopy to the understory (Table 7, Figure 27). The overstory canopy reduced understory light to about 45% of full sunlight, with understory competition in the herbaceous control treatment reducing light to levels as low as 20%. These reductions in radiation resulted in a trend toward slightly higher mean daily Ta and Ts and lower mean midday VPD in the shelterwood, as compared with

Table 5. Summary of cover values (%) for major vegetation groups present on the shelterwood sites at the end of the 2rd growing season. Year 2 restoration site statistics are shown for comparison.

Site	Treatment	Ferns	Grass	Forbs	Low Shrubs	Deciduous	Total Veg Cover	Planted Pine	*n* plots
ON	None	23	4	36	3	14	68	1	24
Shelterwood	Woody	16	7	37	1	<1	57	1	3
	Herbaceous	0	0	<1	0	18	21	2	36
	Woody+Herbaceous	0	0	<1	0	0	1	2	9
NB	None	49	1	17	2	11	72	-	24
Shelterwood	Woody	54	<1	19	4	<1	69	-	3
	Herbaceous	0	<1	<1	<1	12	15	-	36
	Woody+Herbaceous	0	<1	<1	0	0	3	-	9
ON	None	60	9	11	23	8	84	1	24
Restoration	Woody	36	2	7	19	0	55	1	3
	Herbaceous	<1	<1	<1	<1	25	15	2	36
	Woody+Herbaceous	0	<1	0	0	0	1	2	9

Table 6. Summary of growth statistics for planted white pine on the shelterwood sites at the end of the 2rd growing season. Year 2 restoration site statistics are shown for comparison.

Site	Treatment	Health Code[1]	D5[2] (mm)	SE[3]	HT[4] (cm)	SE	SVI[5] (cm^3)	SE	CD[6] (cm)	SE
ON	None	1.3	5.8	0.2	41.3	0.8	4.1	0.6	26.1	0.9
Shelterwood	Woody	1.2	6.8	0.6	44.1	2.2	6.0	1.8	27.1	2.6
	Herbaceous	1.2	7.8	0.2	43.8	0.6	8.0	0.5	32.1	0.7
	Woody+Herbaceous	1.2	9.1	0.4	43.9	1.3	11.1	1.0	32.4	1.5
	Original seedlings, Multipot 67 1-0:		2.4	-	10.4	-	0.2	-	-	-
NB	None	1.4	5.6	0.3	33.0	1.0	4.0	0.7	22.9	1.0
Shelterwood	Woody	1.5	4.7	1.0	29.2	2.7	3.0	2.0	19.1	2.9
	Herbaceous	1.6	6.7	0.3	26.3	0.8	5.3	0.6	22.6	0.8
	Woody+Herbaceous	1.6	7.3	0.6	28.6	1.6	5.9	1.2	24.1	1.7
	Original seedlings, Jiffy 165 1-0:		1.4	-	8.5	-	0.2	-	-	-
ON	None	2.3	6.0	0.2	23.6	0.7	2.6	0.4	16.2	0.6
Restoration	Woody	2.6	7.1	0.5	21.1	1.9	3.0	1.0	15.0	1.6
	Herbaceous	1.7	8.3	0.1	27.3	0.5	5.8	0.3	22.3	0.5
	Woody+Herbaceous	1.8	10.1	0.3	26.9	1.1	8.6	0.6	21.2	0.9
	Original seedlings, Multipot 67 1-0:		3.0	-	11.0	-	0.3	-	-	-

[1] Average of rankings ranging from 1=Vigorous, 2=Healthy, 3=Mediocre, 4=moribund, and 5=dead.
[2] Stem diameter, measured 5 cm above ground level.
[3] Standard error of the least squares mean.
[4] Stem height, measured from ground level to the tip of the terminal bud.
[5] Stem volume index, assuming conical form.
[6] Crown diameter.

Table 7. Summary of seasonal averages for above- and below-ground environmental variables on the Ontario shelterwood site during the 2nd (2003) growing season (Soil Moisture Content also provided for 2002). Means followed by the same letter are not significantly different (Tukey's HSD, $\alpha = 0.05$).

Treatment	PPFD[1] (mol d^{-1})	Ta[2] (°C)	VPD[3] (kPa)	Ts[4] (°C)	SMC[5] 2002 (%)	SMC[5] 2003 (%)
OO	12.7b	15.0a	0.98a	14.8ab	12.4a	12.1a
WW	14.7a	14.7a	0.94a	14.6b	14.0a	14.7a
HH	6.2c	14.9a	0.99a	15.0ab	17.2a	15.6a
BB	14.0ab	15.0a	0.98a	15.8a	17.8a	17.2a

[1] PPFD = Light intensity (photosynthetic photon flux density) measured 0.5 m above ground level.
[2] Ta = Air temperature measured at 0.5 m above ground level.
[3] VPD = Vapour pressure deficit measured at 0.5 m above ground level.
[4] Ts = Soil temperature measured at 5 cm depth in the mineral soil.
[5] SMC = Soil moisture content averaged over the top 15 cm of mineral soil during mid-summer drought period, July 31 – September 10 (2002) and August 5 – September 15 (2003)

Table 8. Summary of seasonal mean values for leaf gas exchange and water status of white pine seedlings on the Ontario shelterwood site during the 2nd growing season. Means followed by the same letter are not significantly different (Tukey's HSD, $\alpha = 0.05$).

Treatment	Pn[1] (umol CO_2 m^{-2} s^{-1})	Gwv[2] (mmol H_2O m^{-2} s^{-1})	WUE[3] (umol CO_2 umol H_2O)	LWPpd[4] (MPa)	LWPmid[5] (MPa)
OO	3.59b	76.1b	55.5a	-0.60a	-1.33a
WW	4.68ab	92.0b	55.6a	-0.59a	-1.26a
HH	4.10ab	92.4b	48.9a	-0.53a	-1.30a
BB	6.02a	120.5a	51.2a	-0.57a	-1.45a

[1] Pn = Net photosynthesis at midday.
[2] Gwv = Laf conductance of water vapour at midday.
[3] WUE = Water use efficiency (ratio of CO_2 fixed in photosynthesis to H_2O transpired) at mid day.
[4] LWPpd = Leaf water status measured before sunrise.
[5] LWPmid = Leaf water status measured at midday.

the clearcut (Tables 7 and 3). As well, the shelterwood exhibited less diurnal amplitude in Ta and Ts due to the strong influence of the overstory canopy on site radiation exchange with the atmosphere (Figure 27). Although treatment patterns were similar, vegetation control did not significantly influence mean SMC during periods of reduced rainfall, as found for the restoration site, due in part to the relatively high variation in SMC exhibited among plots within treatments (Figure 28).

The effects of vegetation control on seedling light availability were also exhibited in the relationship between mean daily percent sunlight and percent cover of competing vegetation (Figure 29). In contrast with findings for the restoration site, maximum height growth of pine generally occurred only where complete control of understory vegetation was achieved, while positive shoot growth was obtained where cover was reduced to 50-60% (e.g., WW) (Tables 5 and 6). The effect of vegetation control on light availability is also evident in treatment effects on plant gas exchange, with Pn and Gwv being significantly greater in the complete vegetation control plots than in untreated plots (Table 8, Figure 30). Although vegetation control had little effect on soil moisture availability in the shelterwood, a significant, negative relationship was observed between SMC and plot basal area, again indicative of the prominent influence of the overstory canopy on the seedling environment (Figure 30).

Presentations and technology transfer activities 2003

- *An introduction to vegetation management and the McConnell Lakes White Pine Competition Studies.* Field presentation delivered to members of the Local Citizen's Committee, Nipissing Naturalist Club (informed public), Scouts and Girl Guides, retired forestry workers, and other interested public, May 3, 2003, North Bay, ON.

- *Uniform shelterwood harvest in white pine – a study of competition and regeneration.* Invited presentation at the Ontario Tree Marker's Certification Course, May 20, 2003, Canadian Ecology Centre, Mattawa, ON.

- *An introduction to vegetation management and the McConnell Lakes White Pine Competition Studies.* Field presentation delivered to the Local Citizen's Committee, forest management advisory body, Nipissing District, June 19, 2003, North Bay, ON.

- *Effects of vegetation management on early conifer establishment and growth.* Presentation and field tour for members of the Living Legacy Trust board of directors, June 23, 2003, North Bay, ON.

- *An introduction to vegetation management and the McConnell Lakes White Pine Competition Studies.* Field presentation delivered to high school and elementary school teachers from across North America attending a joint initiative of the Temperate Forest Foundation, the Forestry Research Partnership, and the Canadian Ecology Centre. August 21, 2003, North Bay, ON.

- *Response of eastern white pine to early herbaceous and woody vegetation control.* Poster presented at the XII World Forestry Congress, Sept. 21-28, 2003, Québec City, QU.

- *An introduction to the White Pine Competition Studies; what results will mean to policy and best-practice development.* Field presentation delivered at the Ontario Ministry of Natural Resources Science Director's Tour, October 15, 2003, North Bay, ON.

- *A study of the effects of woody and herbaceous vegetation on white pine establishment, growth, and stem quality.* Presentation and Proceedings of the Spray Efficacy Research Group Annual Workshop, Oct. 19-23, 2003, Prince Albert, SK. pp. 152-156.

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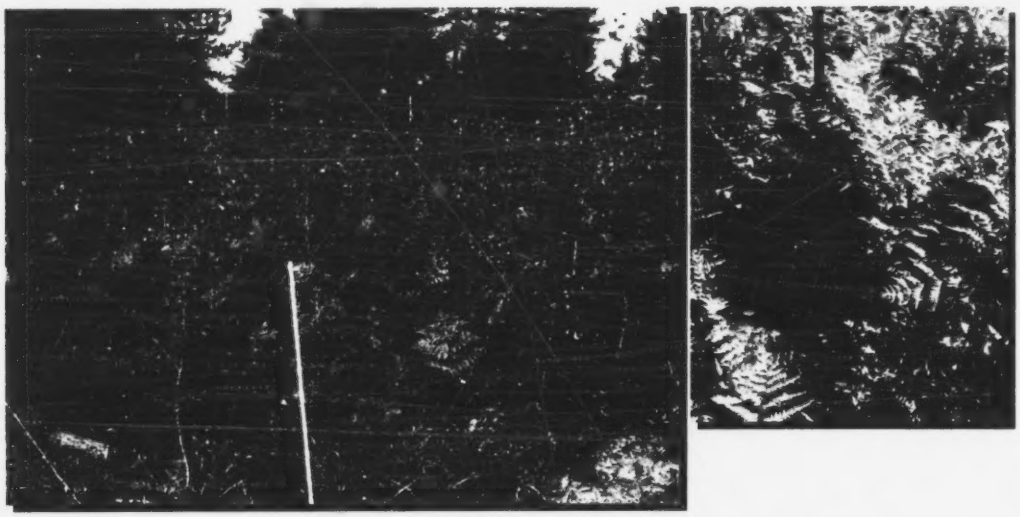

Figure 6. View of a restoration plot receiving no vegetation control during the first 3 growing seasons (treatment code HHH). Photo taken August, 2003.

Figure 7. View of a restoration plot receiving woody vegetation control during the first 3 growing seasons (treatment code WWW). Photo taken August, 2003.

Figure 8. View of a restoration plot receiving herbaceous vegetation control during the first 3 growing seasons (treatment code OOO). Photo taken August, 2003.

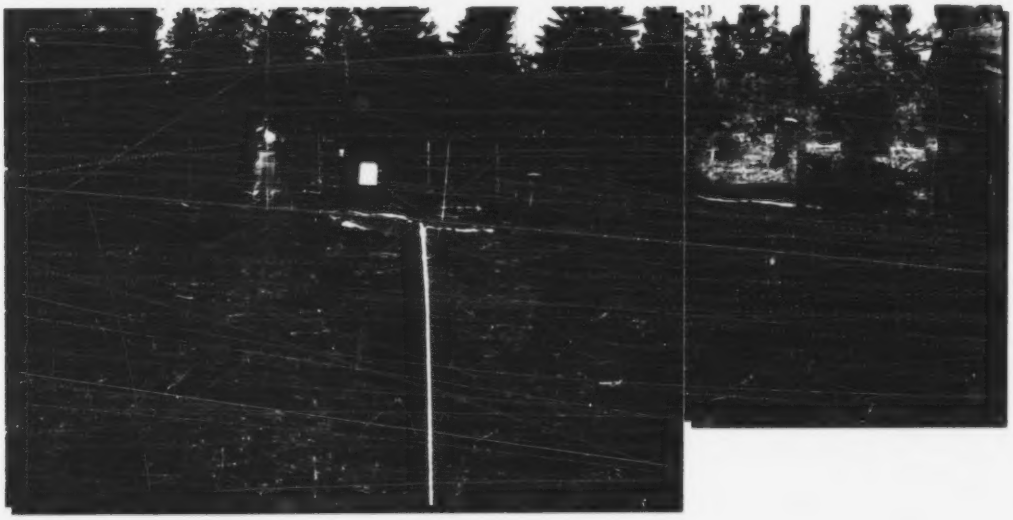

Figure 9. View of a restoration plot receiving total non-crop vegetation control during the first 3 growing seasons (treatment code BBB). Photo taken August, 2003.

Figure 10. View of a restoration plot receiving total non-crop vegetation control during the first 2 growing seasons (treatment code BBW). Photo taken August, 2003.

Figure 11. View of a restoration plot receiving broadcast release after the 2nd growing season (operational reference treatment, code 00B). Photo taken August, 2003.

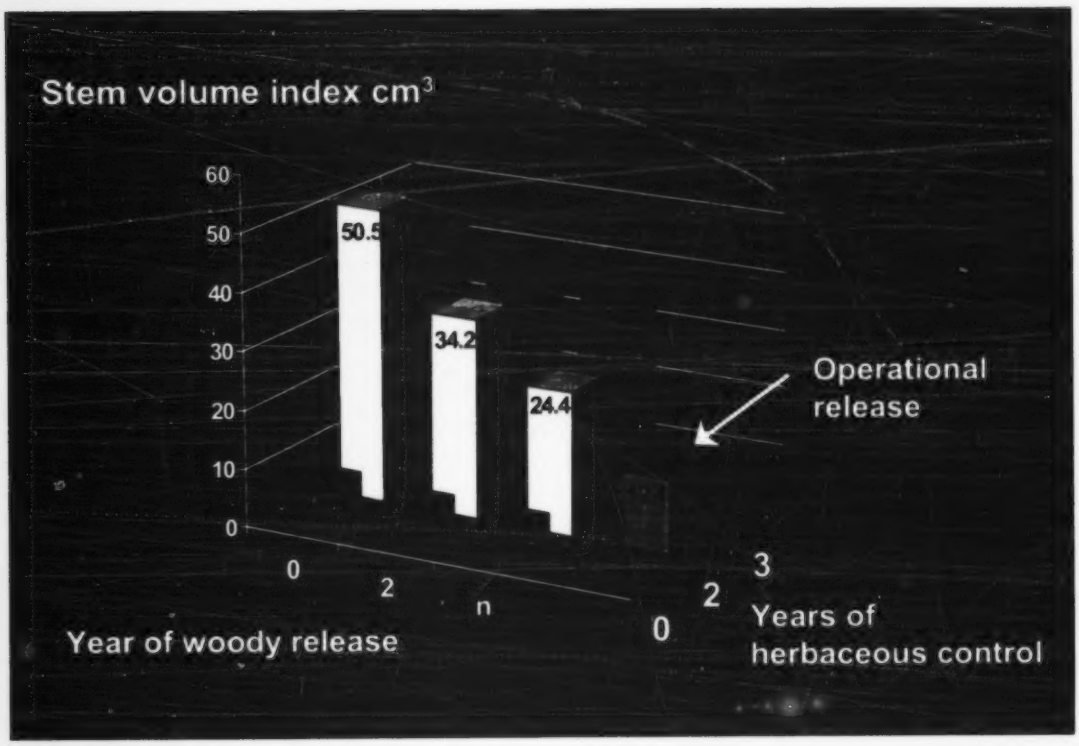

Figure 12. Stem volume index (cm^3/tree) of white pine seedlings on the Ontario restoration site after 3 growing seasons.

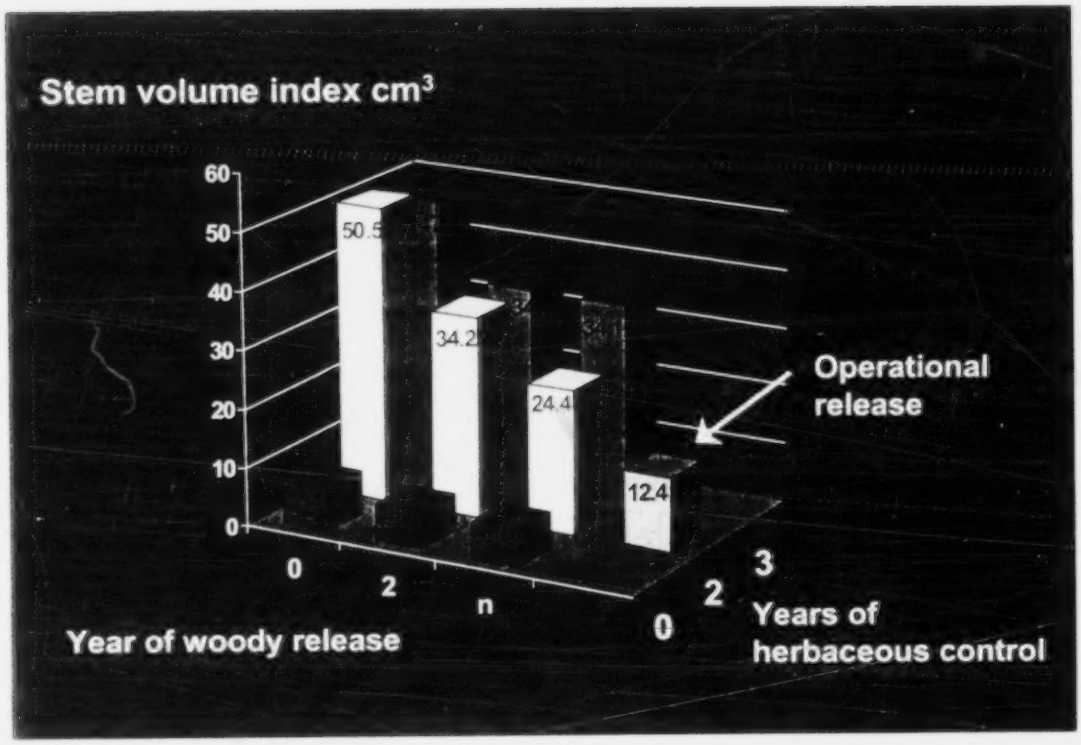

Figure 12. Stem volume index (cm^3/tree) of white pine seedlings on the Ontario restoration site after 3 growing seasons.

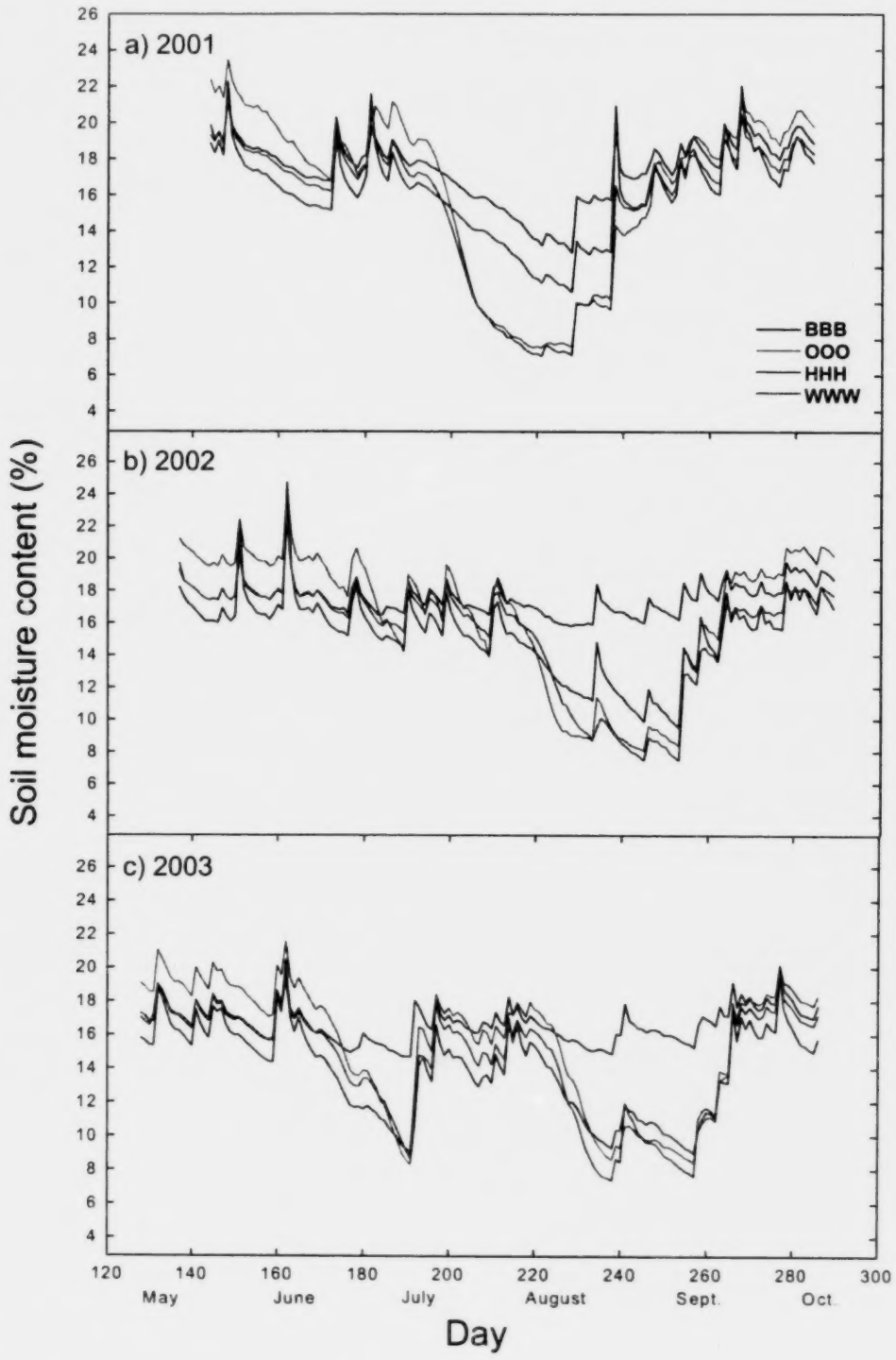

Figure 13. Seasonal variation in mean volumetric soil moisture content (top 15 cm of mineral soil) for the "4-corner" vegetation control treatments on the Ontario restoration site.

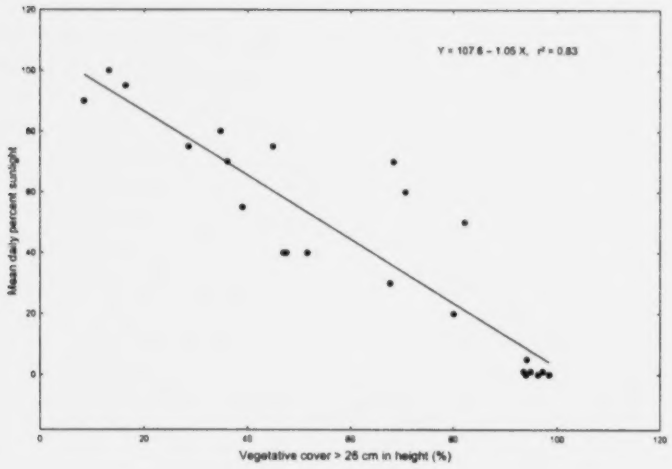

Figure 14. Mean daily percent sunlight vs. percent vegetation cover on the Ontario restoration site during the 3rd growing season. Both readings taken at 26 cm above ground level; mean 2002 seedling height.

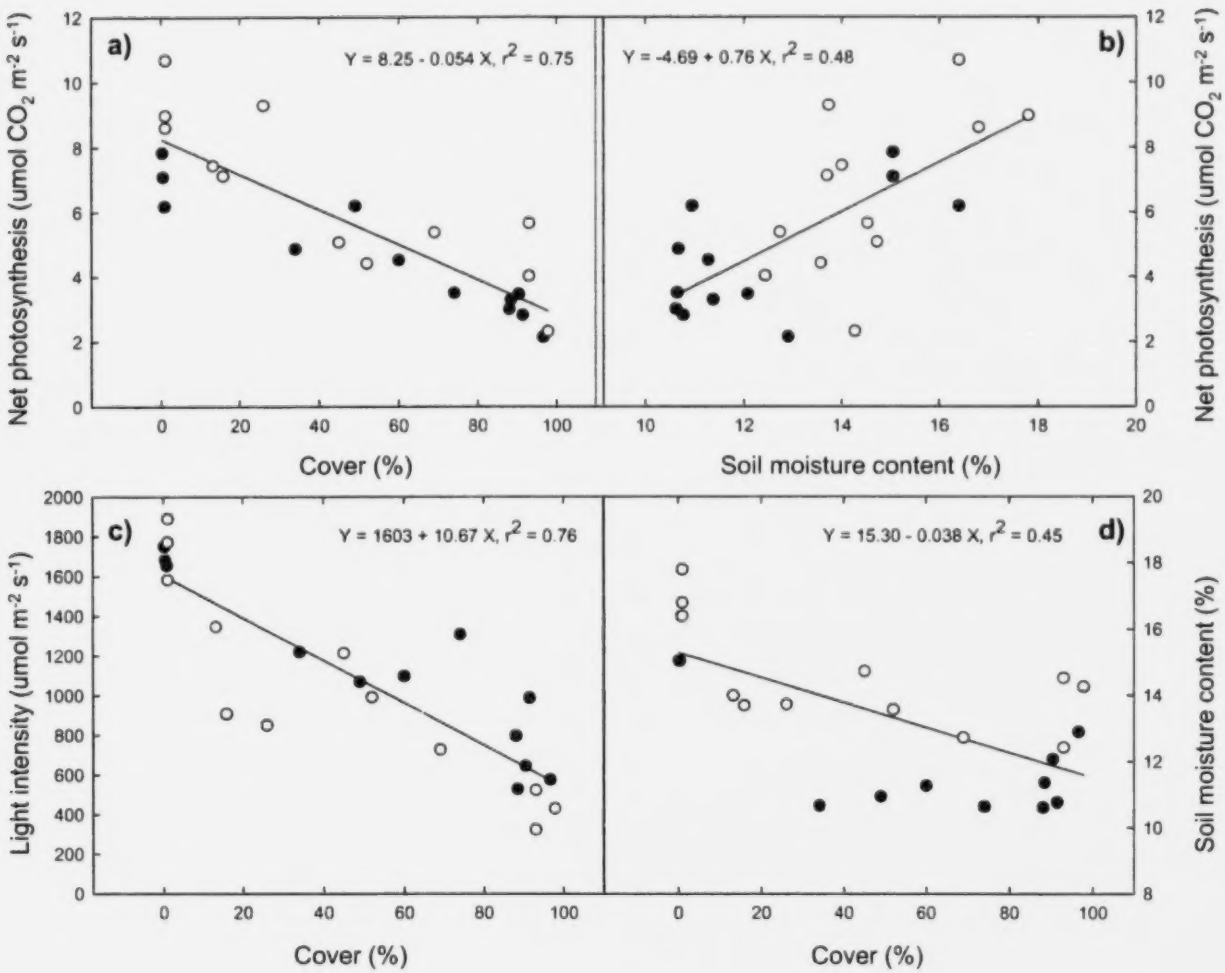
a)
Y = 8.25 - 0.054 X, r2 = 0.75
b)
Y = -4.69 + 0.76 X, r2 = 0.48
Net photosynthesis (umol CO2 m-2 s-1)
Cover (%)
Soil moisture content (%)
c)
Y = 1603 + 10.67 X, r2 = 0.76
d)
Y = 15.30 - 0.038 X, r2 = 0.45
Light intensity (umol m-2 s-1)
Soil moisture content (%)

Figure 15. Net photosynthesis of white pine seedlings vs. (a) cover of competing vegetation and (b) soil moisture content, and (c) light intensity and (d) soil moisture content vs. cover of competing vegetation, on the Ontario restoration site during the 2nd (open circles) and 3rd (solid circles) growing seasons. Each point represents the plot mean for 3 (2nd season) or 4 (3rd season) measurement days.

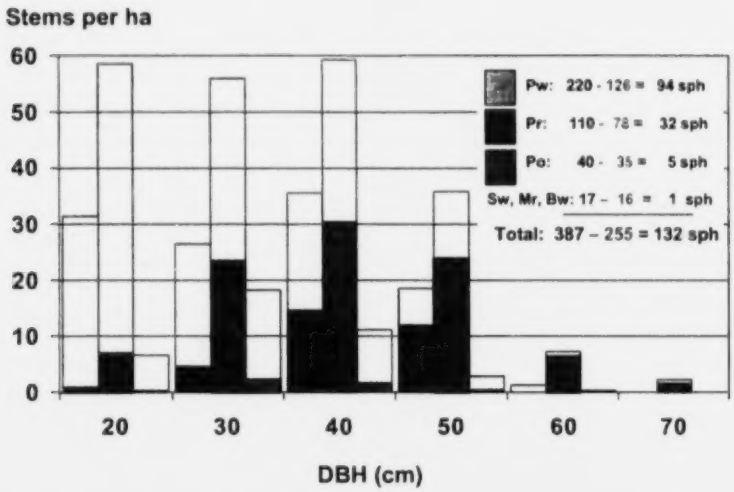

Figure 16. **Diameter distribution of Ontario white pine stand before (transparent bars) and after (colored bars) the shelterwood cut. Data are based on a total enumeration of study area (4 ha).**

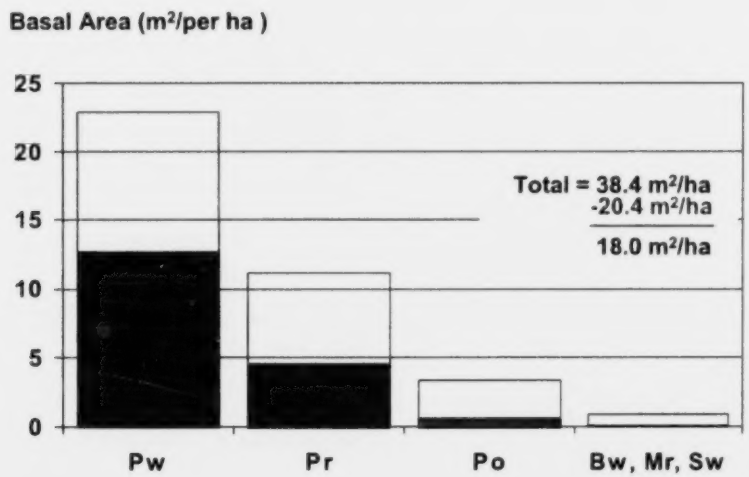

Figure 17. **Basal area distribution of Ontario white pine stand before (transparent bars) and after (colored bars) the shelterwood cut. Data are based on a total enumeration of the study area (4 ha).**

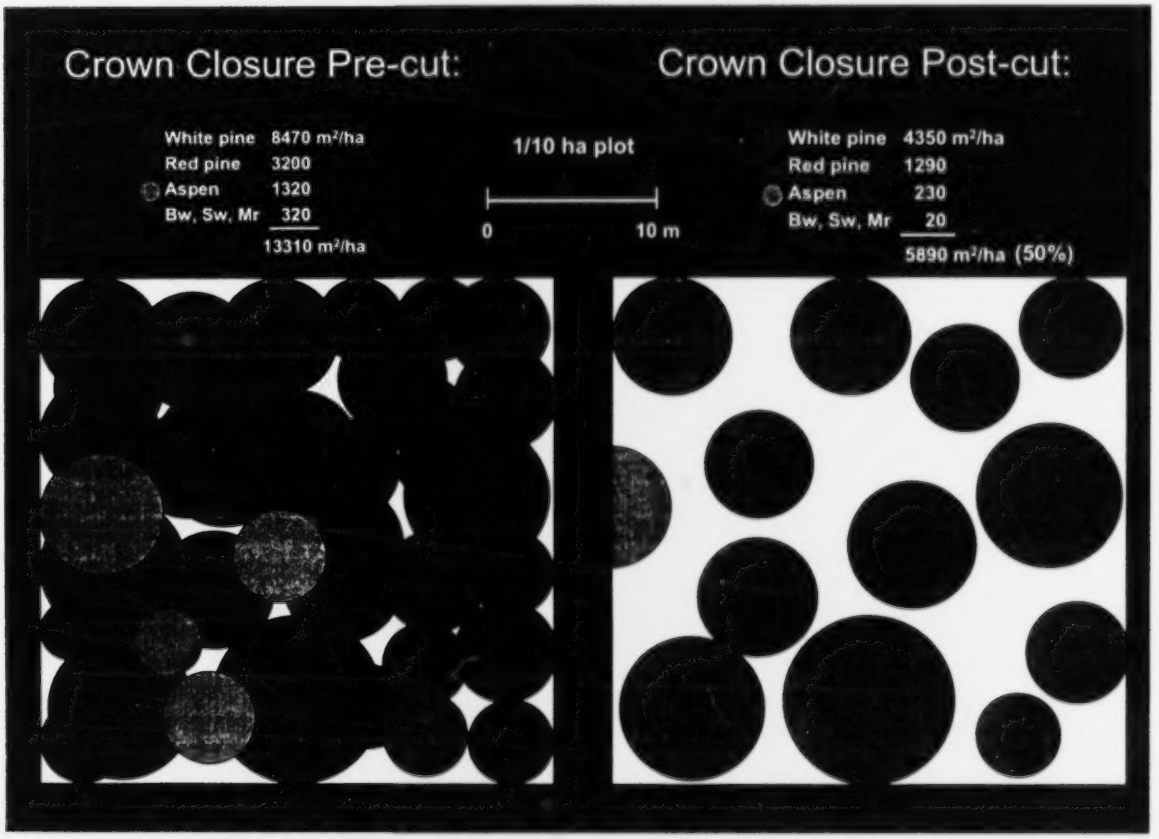

Figure 18. Schematic diagram of crown closure on an average 1/10-ha plot at the Ontario site before and after shelterwood cutting. Data are based measurements of all trees on 4 ha.

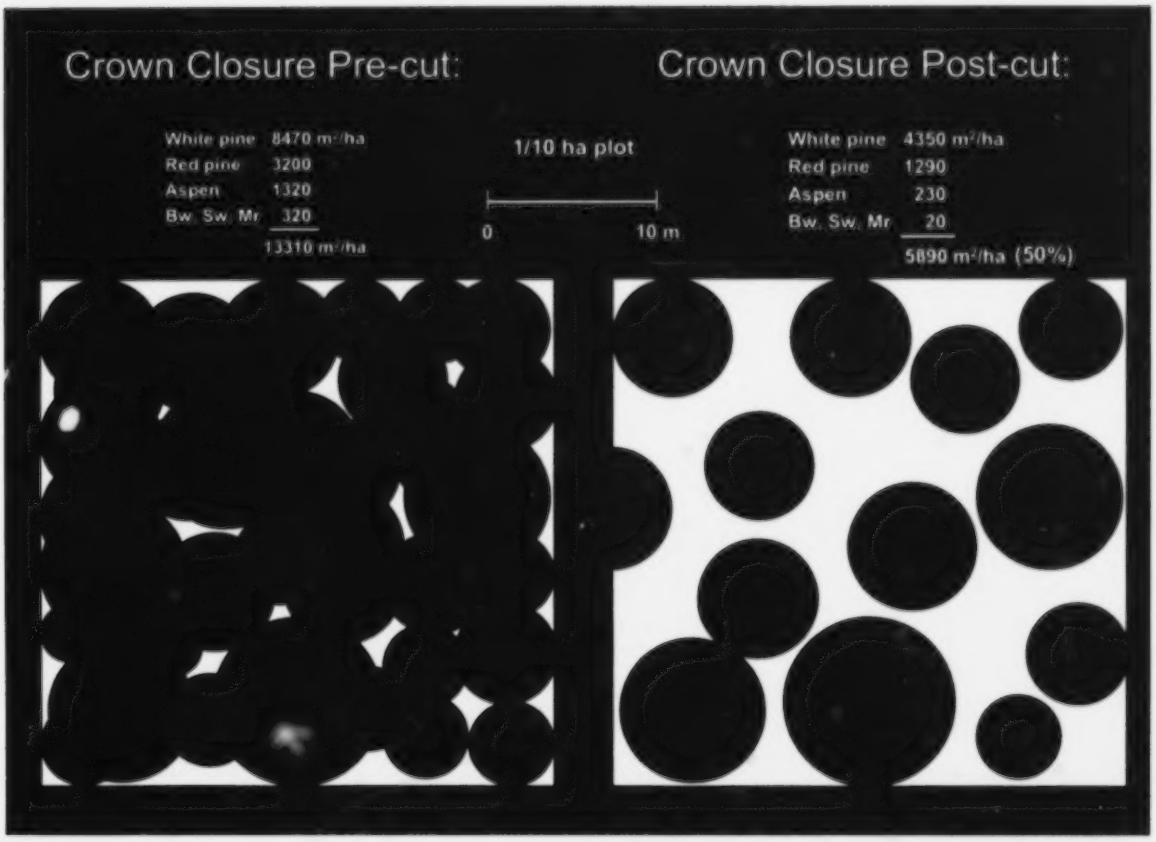

Figure 18. Schematic diagram of crown closure on an average 1/10-ha plot at the Ontario site before and after shelterwood cutting. Data are based measurements of all trees on 4 ha.

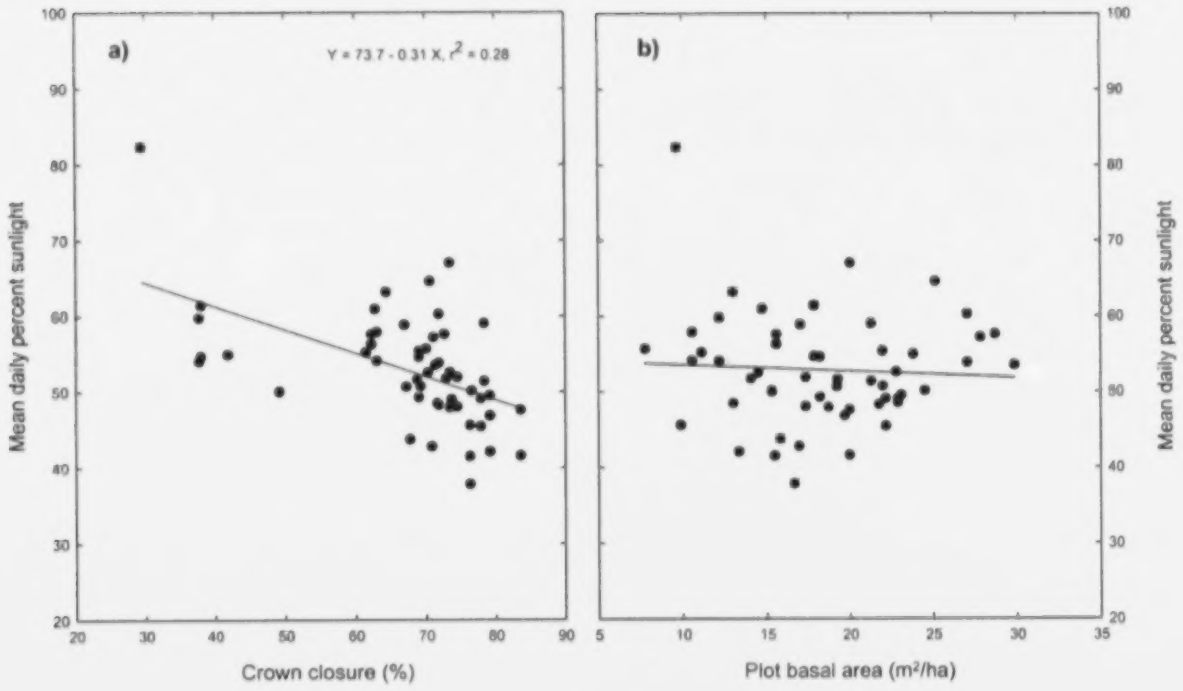

Figure 19. Mean daily percent sunlight vs. (a) overstory percent crown closure (measured by spherical densiometer) and (b) overstory plot basal area on the Ontario shelterwood site.

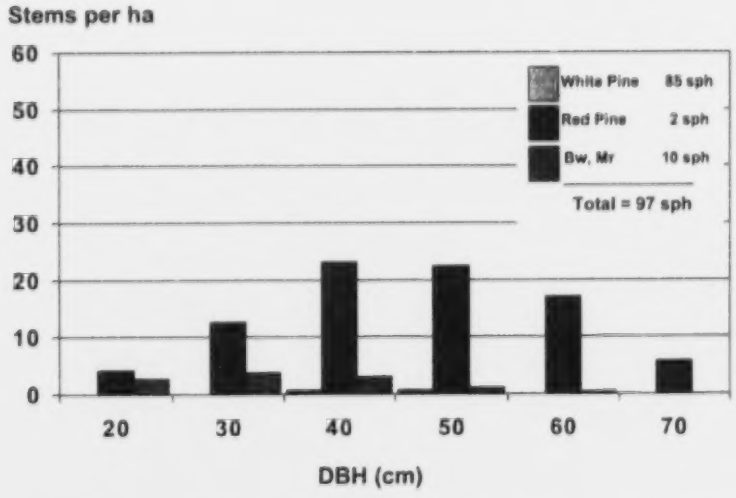

Figure 20. Diameter distribution of New Brunswick white pine stand after the shelterwood cut. Data are based on a total enumeration of study area (3 ha) (axes scaled identical to Figure 16).

Figure 21. View of an Ontario shelterwood plot receiving no vegetation control during the first 2 growing seasons (treatment code OO). Photo taken August, 2003.

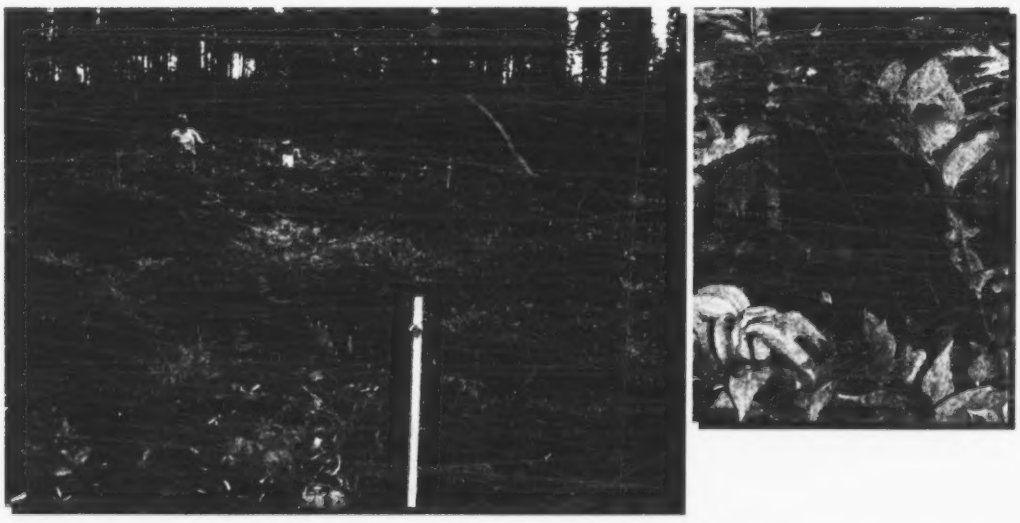

Figure 22. View of an Ontario shelterwood plot receiving woody-only vegetation control during the first 2 growing seasons (treatment code WW). Photo taken August, 2003.

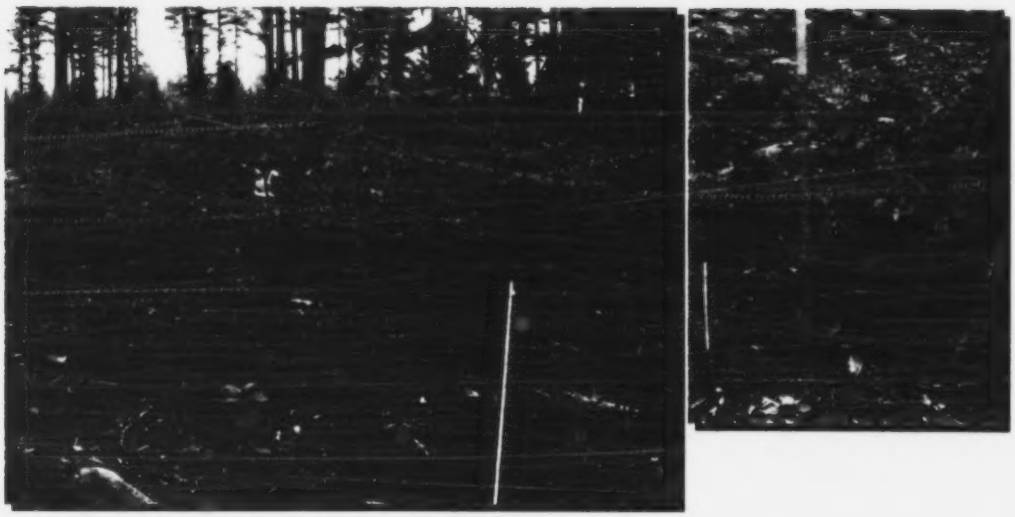

Figure 23. View of an Ontario shelterwood plot receiving herbaceous-only vegetation control during the first 2 growing seasons (treatment code HH). Photo taken August, 2003.

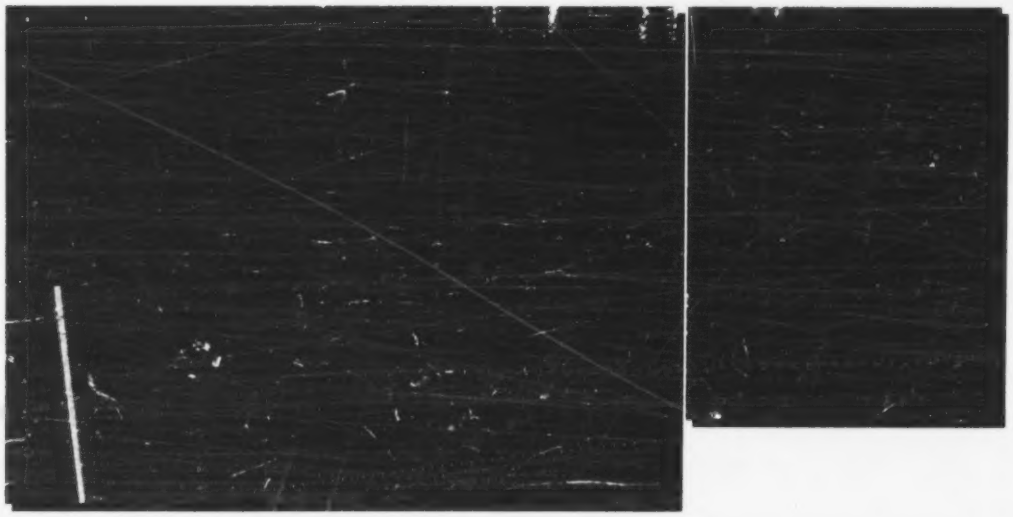

Figure 24. View of an Ontario shelterwood plot receiving total vegetation control during the first 2 growing seasons (treatment code BB). Note the natural pine regeneration in the background. Photo taken August, 2003.

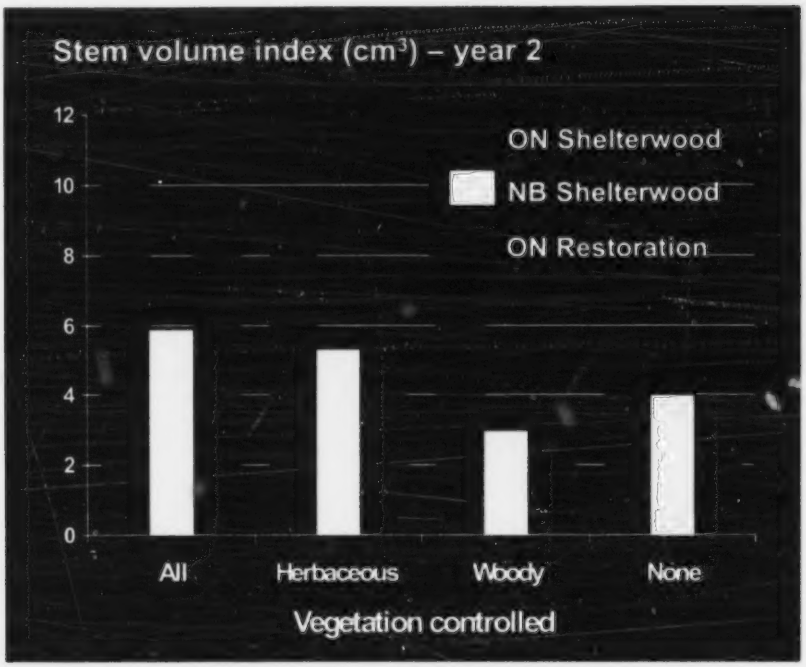

Figure 25. Stem volume index of planted pine after 2 growing seasons at each of the 3 experimental installations.

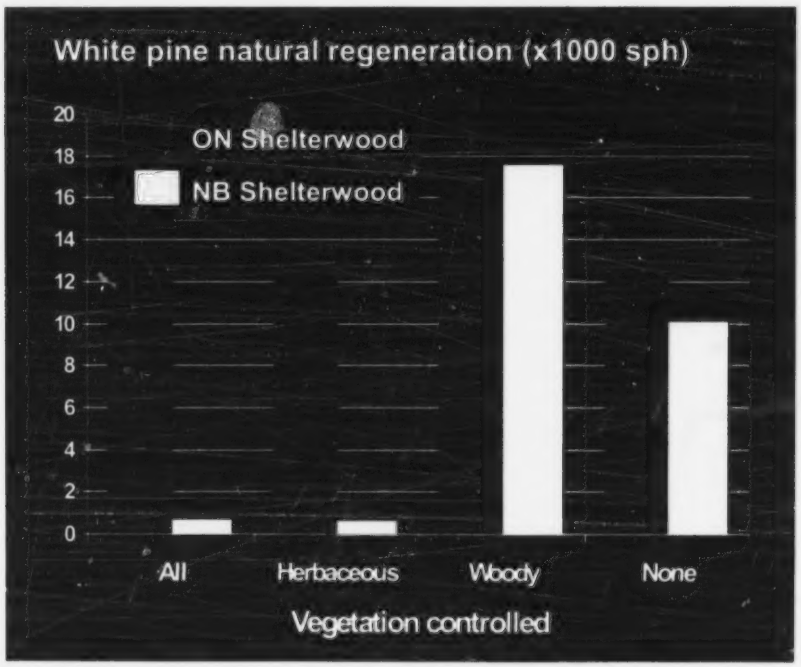

Figure 26. Stem density of natural white pine regeneration after 2 growing seasons at each of the shelterwood installations.

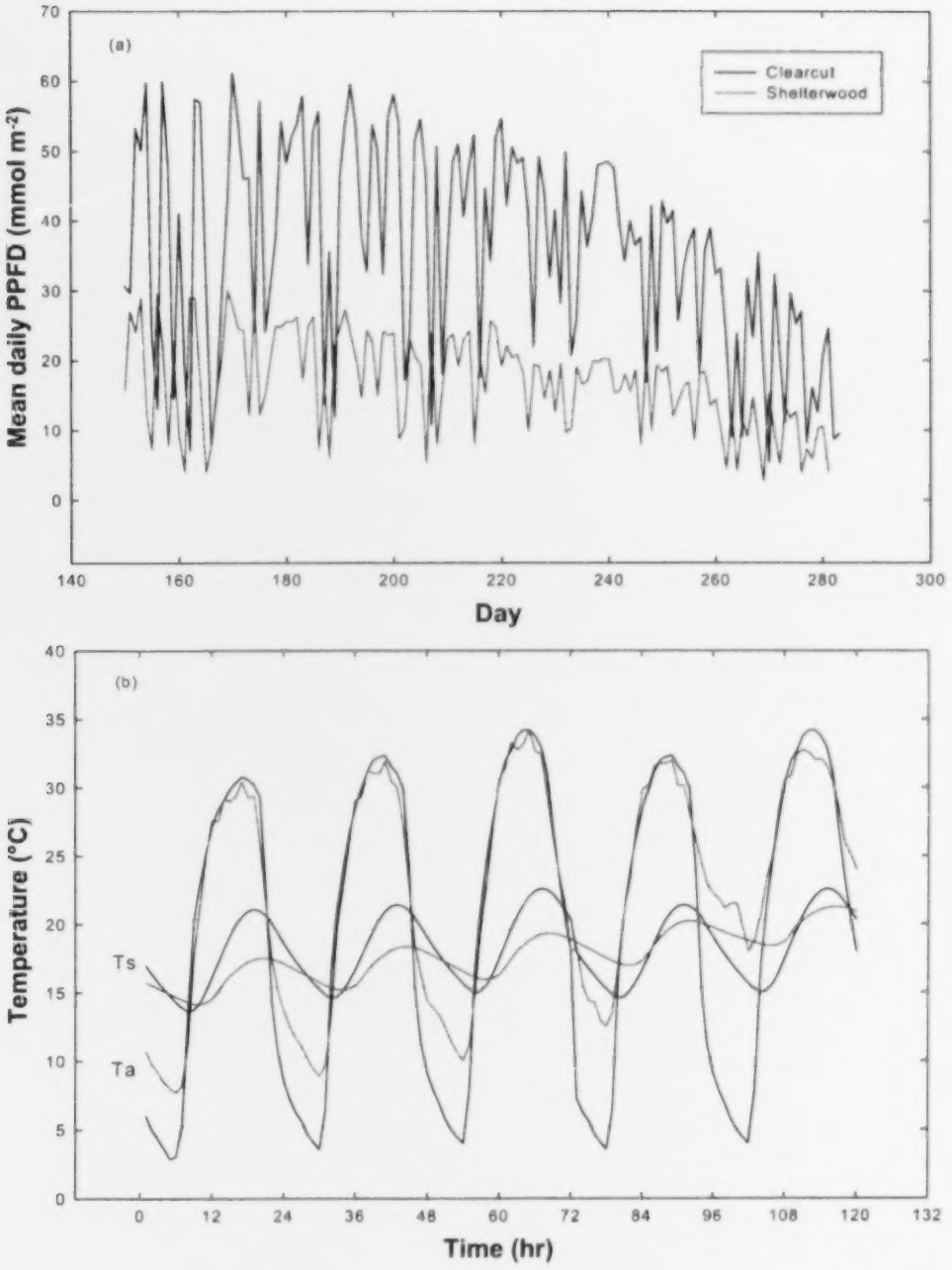

Figure 27. Comparison of (a) seasonal variation in mean daily light intensity (PPFD) and (b) diurnal variation in air (Ta) and soil (Ts) temperature (June 24-28) for the Ontario restoration and shelterwood sites during the 2003 growing season.

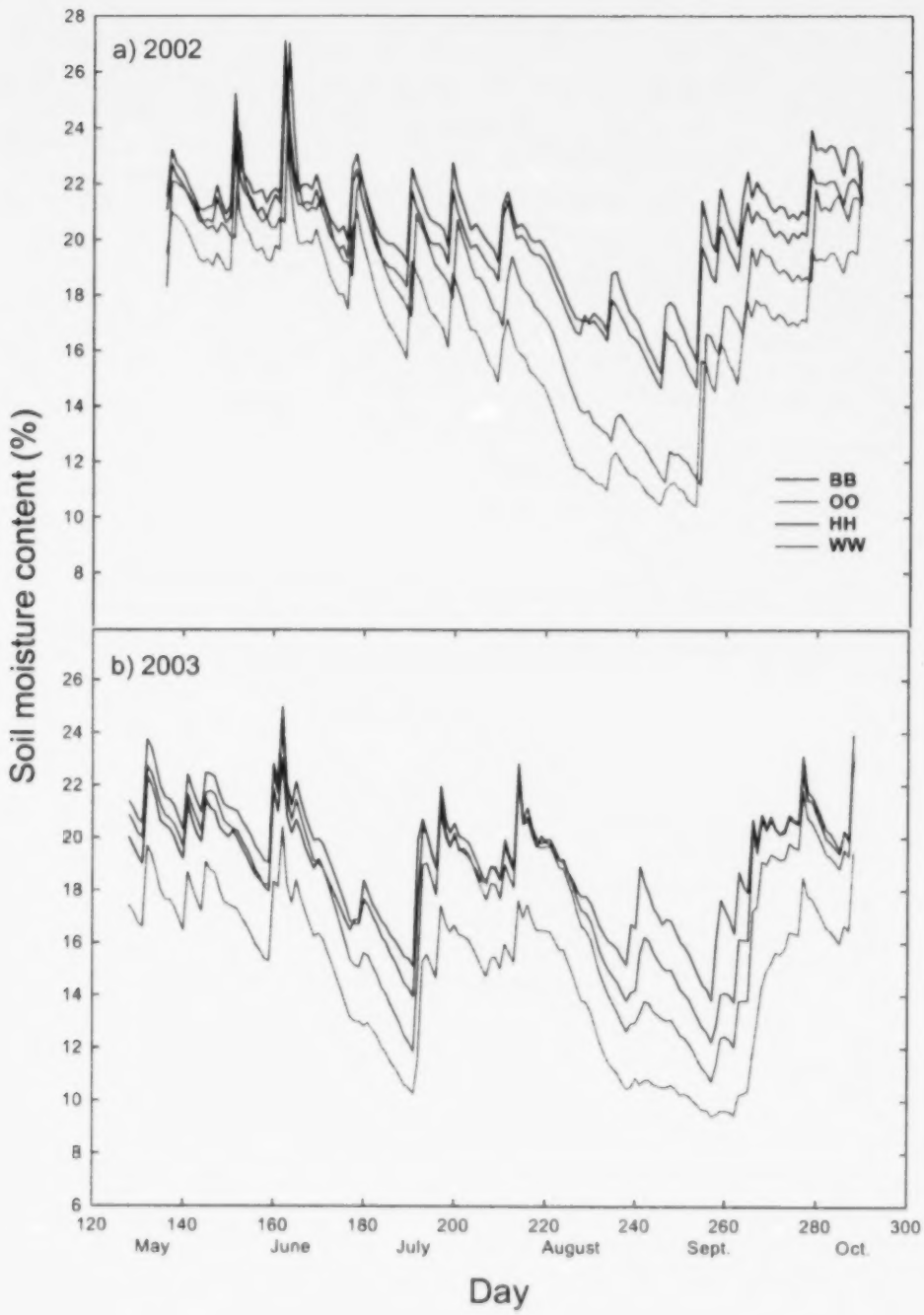

Figure 28. Seasonal variation in mean volumetric soil moisture content (top 15 cm of mineral soil) for the "4-corner" vegetation control treatments at the Ontario shelterwood site.

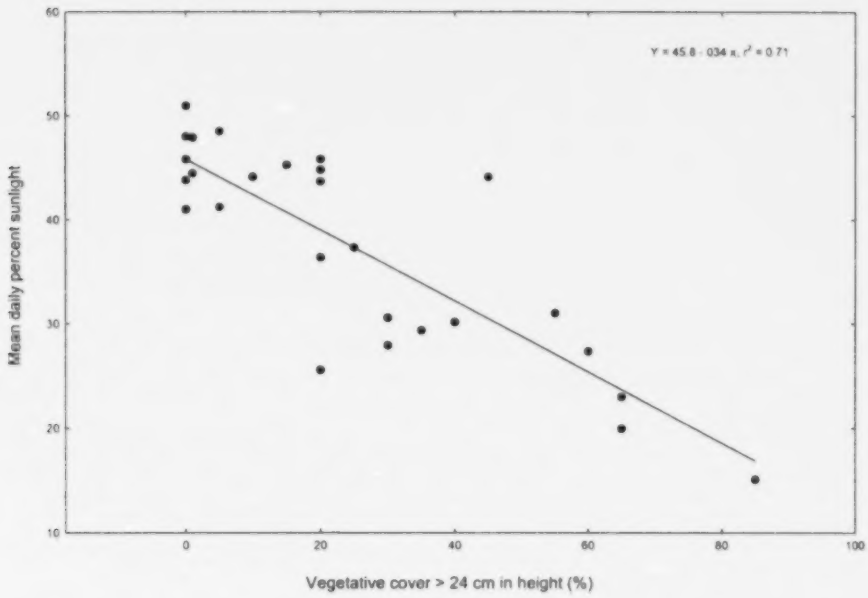

Figure 29. Mean daily percent sunlight vs. percent vegetation cover on the Ontario shelterwood site during the 2nd growing season. Both readings taken at 24 cm above ground level; mean 2002 seedling height.

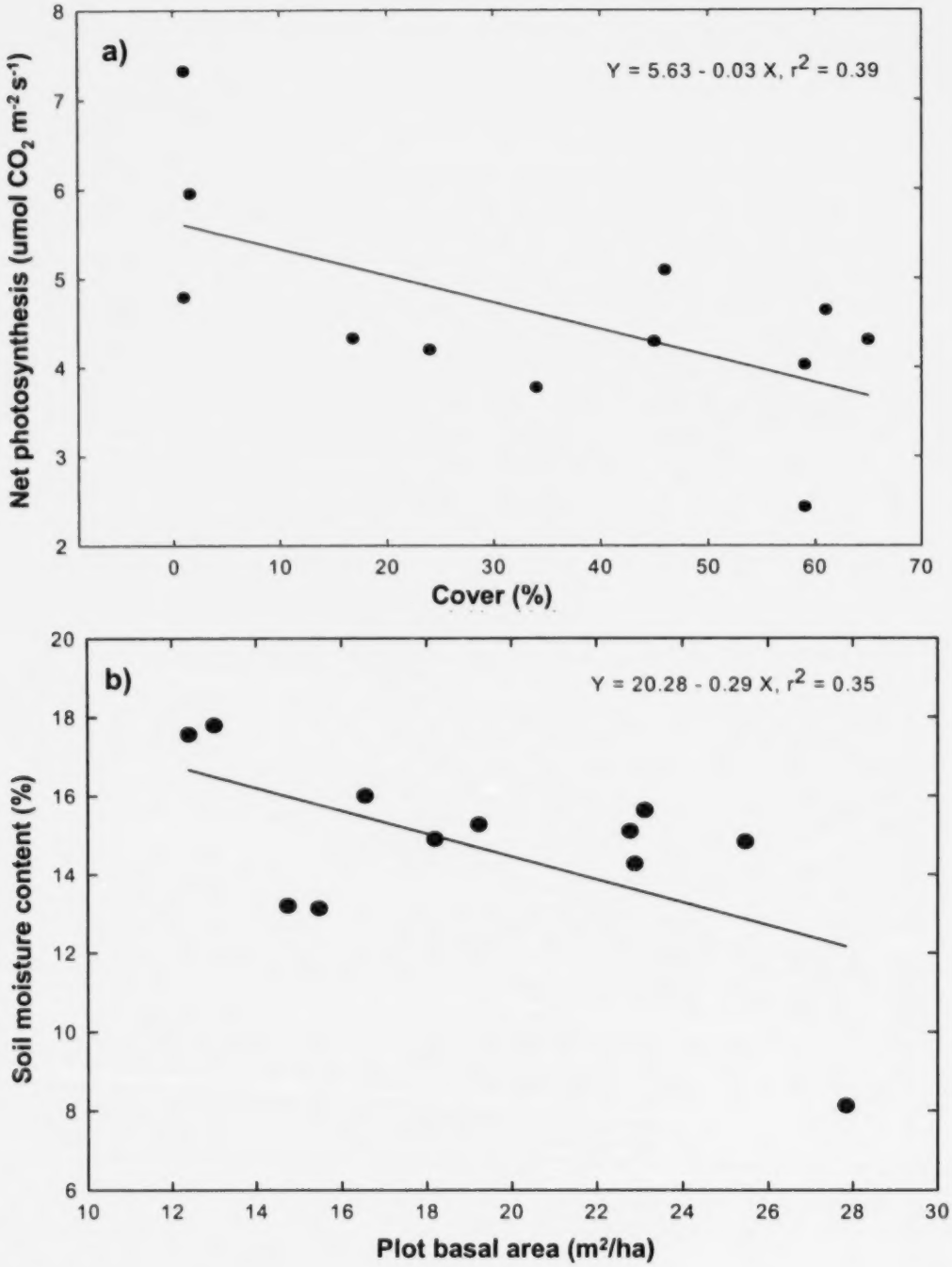

Figure 30. Net photosynthesis vs. understory vegetation cover (a) and soil moisture content vs. overstory plot basal area (b) for the Ontario shelterwood site during the 2nd growing season.